How to build a better PhD

There are too many PhD students for too few academic jobs — but with imagination, the problem could be solved.

BY JULIE GOULD

ILLUSTRATION BY OLIVER MUNDAY

"Since 1977, we've been recommending that graduate departments partake in birth control, but no one has been listening," said Paula Stephan to more than 200 postdocs and PhD students at a symposium in Boston, Massachusetts, in October this year.

Stephan is a renowned labour economist at Georgia State University in Atlanta who has spent much of her career trying to understand the relationships between economics and science, particularly biomedical science. And the symposium, 'Future of Research', discussed the issue to which Stephan finds so many people deaf: the academic research system is generating progeny at a startling rate. In biomedicine, said Stephan. "We are definitely producing many more PhDs than there is demand for them in research positions."

The numbers show newly minted PhD students flooding out of the academic pipeline. In 2003, 21,343 science graduate students in

the United States received a doctorate. By 2013, this had increased by almost 41% — and the life sciences showed the greatest growth. That trend is mirrored elsewhere. According to a 2014 report looking at the 34 countries that make up the Organisation for Economic Co-operation and Development, the proportion of people who leave tertiary education with a doctorate has doubled from 0.8% to 1.6% over the past 17 years.

Not all of these students want to pursue academic careers — but many do, and they find it tough because there has been no equivalent growth in secure academic positions. The growing gap between the numbers of PhD graduates and available jobs has attracted particular attention in the United States, where students increasingly end up stuck in lengthy, insecure postdoctoral research positions (see *Nature* **520,** 144–147; 2015). Although the unemployment rate for people with science doctorates is relatively low, in 2013 some 42% of US life-sciences PhD students graduated without a job commitment of any kind, up from 28% a decade earlier. "But still students continue to enrol in PhD programmes," Stephan wrote in her 2012 book *How Economics Shapes Science*. "Why? Why, given such bleak job prospects, do people continue to come to graduate school?"

One reason is that there is little institutional incentive to turn them away. Faculty members rely on cheap PhD students and postdocs because they are trying to get the most science out of stretched grants. Universities, in turn, know that PhD students help faculty members to produce the world-class research on which their reputations rest. "The biomedical research system is structured around a large workforce of graduate students and postdocs," says Michael Teitelbaum, a labour economist at Harvard Law School in Cambridge, Massachusetts. "Many find it awkward to talk about change."

But there are signs that the issue is becoming less taboo. In September, a group of high-profile US scientists (Harold Varmus, Marc Kirschner, Shirley Tilghman and Bruce Alberts, colloquially known as 'the Quartet') launched Rescuing Biomedical Research, a website where scientists can make recommendations on how to 'fix' different aspects of the broken biomedical research system in the United States — the PhD among them. "How can we improve graduate education so as to produce a more effective scientific workforce, while also reducing the ever-expanding PhD workforce in search of biomedical research careers?" the site asks.

Nature put a similar question to 33 PhD students, scientists, postdocs and labour economists and uncovered a range of opinions on how to build a better PhD system, from small adjustments to major overhauls. All agreed on one thing: change is urgent. "Academia really is going to have to be dragged kicking and screaming into the twenty-first century," says Gary McDowell, a postdoctoral fellow at Tufts University in Medford, Massachusetts, and a leader of the group behind the Future of Research symposium. The renovation needs to happen now, says Jon Lorsch, director of the US National Institute of General Medical Sciences in Bethesda, Maryland. "We need to transform graduate education within five years. It's imperative. There's a lot at stake for scientists, and hence for science."

TRACK THE PHD

One place to begin is with hard facts: show prospective students and supervisors data on trainees' chances of moving into academic research or other careers. Prospective students "aren't thinking strategically about what they really want to do or what they're best suited for", says Patricia Labosky, a programme director for scientific training at the US National Institutes of Health (NIH) in Bethesda, Maryland.

A 2015 *Nature* survey of more than 3,400 science graduate students around the world suggested that many were overly optimistic about their chances in academia. About 78% of respondents said that they were "likely" or "very likely" to follow an academic career, and 51% thought that they would land some type of permanent job in one to three years. In reality, only about 26% of PhD students in the United States move into tenured or tenure-track positions, and getting there can take much longer than this (see 'Ups and downs of PhDs').

But although some data exist about career paths, there are key gaps relating to the range of job opportunities, earnings, time spent as a postdoc and long-term career trajectories, says Julia Lane, an economist at New York University. A January report on post-PhD careers by the US Council of Graduate Schools in Washington DC found that there are no standardized ways to collect information on graduates after they have left their educational institution; only around one-third of universities in the United States and Canada formally compile such data.

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In October, Stanford University in California published the results of a major effort to track graduates either 5 or 10 years after their PhD. It showed that the number of bioscience PhD students progressing to postdoctoral positions had dropped from 41% to 31% in the more recent graduate group, and that many were moving into business, government or non-profit positions. This probably reflects the growing bottleneck in academic jobs and booming opportunities in business.

Lane is leading a more comprehensive effort to track career outcomes in research called UMETRICS, which is based at the University of Michigan in Ann Arbor. By combining anonymized human-resource and administrative data from universities with US Census Bureau data on earnings, places of work and job titles, UMETRICS will be able to produce campus-level reports on the career outcomes of graduate students. A student interested in a chemistry PhD, for example, could scan a campus report and see what previous graduates went on to do, where they went and how much they earn. It will take several years before the first data sets are released, Lane says — but when they are, "the students opting in to graduate schools will go in with eyes wide open".

REVAMP THE PHD

Many PhD students enjoy the intellectual freedom of a PhD for a few years and then successfully move on to other things. But a lot of students want more preparation and training for that step — such as building skills in management, budgeting or negotiation. "Apparently, you have to learn these things somewhere on the side, since you are supposed to spend all your time as a PhD and postdoc doing research," says Joanna Klementowicz, a postdoc at the University of California, San Francisco (UCSF).

The current graduate education system in many countries is based on an apprenticeship model, wherein lab heads train younger researchers in the craft of research. This system has been prominent since the 1800s, when the first 'modern' PhD was awarded by the University of Berlin. Although the scientific enterprise has changed dramatically since then, the PhD system has not.

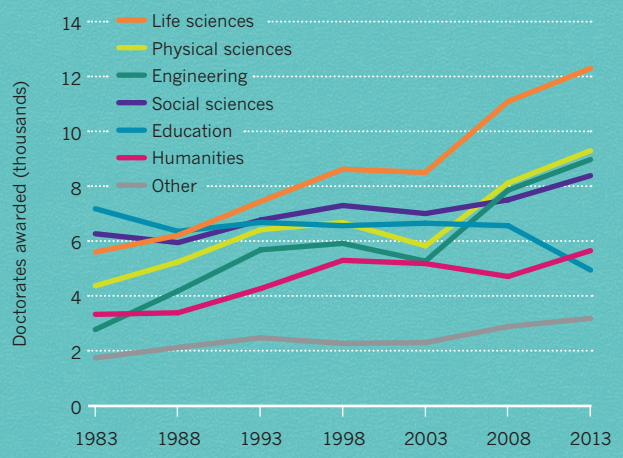
Modernizing the PhD could improve training in areas of research ranging from reproducibility to experimental design and entrepreneurship. It could also help to solve the bottleneck problem by equipping doctorate holders with soft skills that make them more employable wherever they go. "We need to tailor graduate education to meet the needs of students without violating what it means to be a scientist," says Alan Leshner, chief executive emeritus of the American Association for the Advancement of Science in Washington DC.

Some funding bodies and research institutions have already taken this on board. In 2013, the NIH started the Broadening Experiences

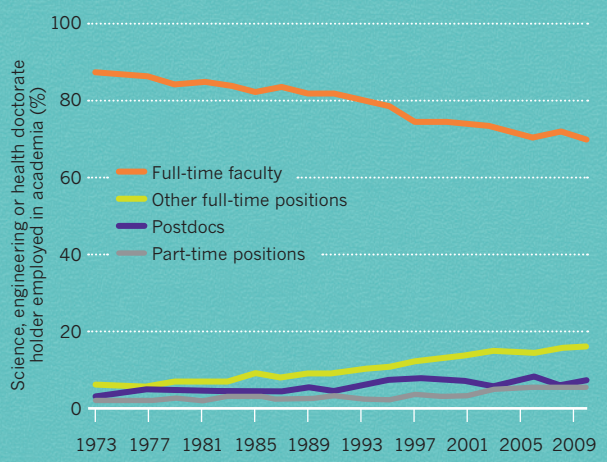
UPS AND DOWNS OF PHDS

The number of students in the United States who graduate with a doctorate has increased, with the most rapid rise in life-sciences degrees. The proportion of PhDs in permanent academic positions is falling, and the number graduating with no job or postdoc lined up is on the rise.

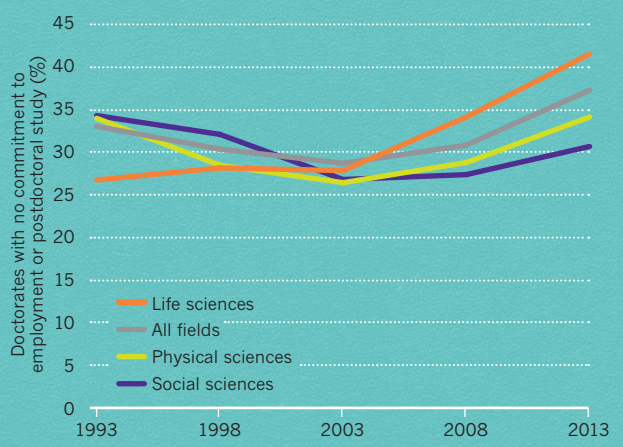
DOCTORATES AWARDED



DOCTORATES IN ACADEMIA



DOCTORATES' CAREER PLANS



SOURCE: NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS

in Scientific Training (BEST) initiative — a US$3.7-million programme that is designed to improve training for biomedical PhDs and postdocs. "We got a lot of feedback from [employers] that the graduates weren't ready for careers outside of academia," says Labosky, who heads the programme.

At UCSF, PhD students on the BEST programme spend nine months training in areas such as management, interviewing and networking, and are put into groups that work together to explore career objectives. "The programme made me practical: I learned to look out for what I can apply for, what my skills were matched to and what people with a PhD like mine go on to do," says Klementowicz, who took the programme as a postdoc.

Some scientists would like to see particular emphasis put on teamwork to reflect the increasingly collaborative nature of research. David Golan, dean of graduate education at Harvard Medical School in Boston, Massachusetts, is considering how to ingrain teamwork more deeply into the graduate-school experience. "We have toyed with the idea of having students form a team before they apply to grad school," he says. They might then be given a project to work on together throughout their training — and perhaps even be examined together.

SPLIT THE PHD

There may be too many PhD graduates for academia, but there is plenty of demand for highly educated, scientifically minded workers elsewhere. So some scientists propose that the PhD should be split into two: one for future academics and a second to train those who would like in-depth science education for use in other careers.

Biologist Anthony Hyman, director of the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, Germany, is one of those who thinks that a split PhD might work. Students in the academic-track PhD would focus on blue-skies research and discovery, he says. A vocational PhD would be more structured and directed towards specific careers in areas such as radiography, machine learning or mouse-model development.

A similar concept already exists in engineering: students in the United Kingdom, the United States, France and Germany can choose to study for either an academic-style PhD in engineering or a doctorate in engineering (EngD), which is designed with industrial careers in mind and often involves a supervisor in industry alongside one in academia. David Stanley, who manages an EngD programme that focuses on nuclear engineering at the University of Manchester, UK, says that the programme is aimed at supplying industry with employees. "Graduates with an EngD are highly valued in industry, more than those with PhDs, because of their extended training," he says.

Elsewhere, industrial PhDs are taking shape in the biomedical sciences. One of the oldest government-organized industrial PhD schemes is run by Innovation Fund Denmark, which supports students who are simultaneously enrolled at a Danish university and employed (and paid) by a private-sector company. Melanie Sinche, director of education at the Jackson Laboratory for Genomic Medicine in Farmington, Connecticut, is enthusiastic about the idea of a vocational PhD at her institute, where it might fulfil a need for more expert computational biologists. "The number of people qualified to do this is small, and there are lots of employers competing for this small pool of candidates," she says.

But the split PhD could face challenges if the two tracks are valued in different ways: academics could view a vocational PhD as second-class, whereas tech companies could view an academic PhD as too abstruse for the real world. That could end up limiting the career options of doctorates rather than broadening them, says Hyman. Stanley counters that EngD students do not have that problem. "A couple of students a year find their way back into academia to conduct research," he says.

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SKIP THE PHD

Some scientists call for more drastic measures — cutting down the number of people who pursue a PhD.

Siphoning off more students into master's programmes is one way to reduce PhD numbers, says Bruce Alberts, professor of biochemistry and biophysics in the department of medicine at UCSF. A master's can offer advanced scientific training that is sufficient for many careers, as well as a taste of research, in one or two years rather than the four or five eaten up by a typical PhD. "In an ideal world, everyone would go in for a master's," Alberts says.

Master's degrees are already common across Europe. In the Netherlands, students are required to complete a master's before embarking on a PhD. "There are many who don't want to be in academia who leave with a master's to work in government institutions, companies, in publishing," says Frank Miedema, professor and head of immunology at the University Medical Center Utrecht in the Netherlands. "And a master's is not considered a failure for those who can't make it to a PhD."

Victoria Evans graduated with a master's degree in astrophysics from Cardiff University, UK, in 2012. "The research project in the master's gave me an insight into what a PhD project would be like," she says, "and I came to the conclusion that it wasn't what I wanted to do." She now works as a nuclear-safety engineer for EDF Energy on the west coast of Scotland. "The problem-solving and analytical skills that I learned during my master's were more than sufficient for me to work in this field."

In the United States, the science master's has often had a lower status than the PhD — but universities are now launching more of them. Between 2000 and 2011, the number of science and engineering master's degrees available increased by 57%, compared with a 38% increase in doctoral degrees, according to the US National Science Foundation. Part of that growth has been in the professional science master's degree, a programme developed in the late 1990s as a graduate degree that would simultaneously develop scientific and workplace skills. Last year, Harvard Medical School introduced a two-year master's in immunology aimed at students who want additional classroom and research experience to help them decide whether to continue on to a PhD or MD, or to transition to industry.

But master's programmes are no panacea. Unlike most doctoral students, master's students in the United States and Europe are often required to pay for their tuition, and that could dissuade many from signing up. "This does create a social access problem," said neuroscientist Eve Marder of Brandeis University in Waltham, Massachusetts, at last month's Future of Research meeting.

CUT THE PHDS

Labour economists have been advocating for a reduction in the number of graduate students who enter biomedical sciences for several decades. Yet there is enormous resistance to change. That's what the Quartet found, when it proposed gradually reducing the numbers of PhD students as part of its efforts to rescue biomedical research. "This idea has had the most opposition from our colleagues," says Alberts. Faculty members and research institutions may be especially reluctant to give up the cheap workers who power their research when government funding for biomedicine has fallen, as it has in the United States for the past decade or so. And some scientists argue that fewer PhD graduates would be a loss to science and society as a whole. "The draconian measures of restricting access to graduate school is detrimental to science," said Marder at the Future of Research meeting. "It means we would restrict the imagination in our workforce."

Cuts to PhD programmes haven't gone down well. When the Canadian Institutes of Health Research cancelled its 30-year-old MD/PhD programme earlier this year owing to budget tightening, academics and students reacted with horror. But other fields regulate the flow of students into courses to match supply to demand. The American Bar Association, which oversees the legal system in the United States, attempts to regulate the number of qualified lawyers by exerting strict control over the number of law schools. And bar associations set fiendishly difficult examinations for would-be lawyers to get into law school in the first place.

Stiffer entrance assessments for those who want to pursue a PhD could cut down entrant numbers — if the right criteria can be found. In the United States, Graduate Records Examinations (GREs) are used as a way of selecting entrants for graduate school, but the system is hardly perfect: one survey showed that 37% of US biology PhD students drop out before completing their degree. When Orion Weiner, a molecular biologist at UCSF, did a small, retrospective study of graduate students admitted onto one of his university's biology PhD programmes, he found that previous experience in research and the subject-specific GRE results (but not the analytical, verbal or quantitative elements) were good indicators of future success in graduate school.

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A broader entrance assessment could look at students' experience in communication, management, teamwork and career goals. That could be used to filter students with a passion for academic or industrial research towards PhD programmes and send others into a master's or other types of training, says Bill Lindstaedt, executive director for career advancement at UCSF.

Stephan believes that funding bodies should have a major role in limiting the number of biomedical PhD places to better match supply and demand, and she also proposes that students should contribute to their training costs. "When we have to pay something out of pocket, we think a little more clearly about whether that is a good fit for us," she says. Such ideas may be controversial — but many people say that they have to be considered.

At the heart of the problem, say scientists, is that the community is not discussing the PhD problem enough. "There is a reluctance from supervisors to tell undergrads and grad students the reality of the system," says postdoc McDowell. "The misinformation exists because the system is worried about deflecting smart people from entering." Although principal investigators acknowledge the difficulty of securing an academic position, the system worked for them and so it is tempting to tell students that they can do it too — just another experiment, another publication or another year, and you'll get there.

Grass-roots groups such as Future of Research are calling attention to the issue, as are efforts such as Rescuing Biomedical Research. Meanwhile, some experts say that the onus falls partly on prospective and current PhD students to make sure their eyes are open. They should arm themselves with as much information as possible, says Labosky, so that "they are aware of their alternative options and can make plans".

Stephan does see some prospect that her call for PhD birth control will be heard. She says that change might happen naturally, as more information becomes available on career outcomes, and that flat funding streams could prevent further growth in biomedical PhDs. "Individuals might become less focused on PhD production, and universities and faculty are more likely to pay attention to these recommendations."

Teitelbaum, for his part, does not favour a large cut in biomedical PhDs, and instead prefers a more considered approach. "Find out why people start PhDs and what they think their career prospects are from the very beginning," he says. "Like ballet dancers or actors, if they chose to take it on knowing their chances of becoming a successful professor, then let them carry on." ■ SEE EDITORIAL P.7 AND CAREERS P.155

Julie Gould *is an editor for* Naturejobs.